Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

CSAS | **SCCS**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2012/105 | **Document de recherche 2012/105**

Quebec Region | **Région du Québec**

Reference points for eastern Canadian redfish (*Sebastes*) stocks

Points de référence pour les stocks de sébaste (*Sebastes*) de l'est du Canada

Daniel E. Duplisea[1], Don Power[2] and Peter Comeau[3]

[1]Fisheries and Oceans Canada
850 route de la Mer
Mont-Joli, QC G5H 3Z4

[2]Northwest Atlantic Fisheries Centre
Fisheries and Oceans Canada
St John's, NL A1C 5X1

[3]Bedford Institute of Oceanography
Fisheries and Oceans Canada
Dartmouth, NS B2Y 4A2

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

This document is available on the Internet at

La présente série documente les fondements scientifiques des évaluations des ressources et des écosystèmes aquatiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

Ce document est disponible sur l'Internet à

www.dfo-mpo.gc.ca/csas-sccs

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)
© Her Majesty the Queen in Right of Canada, 2012
© Sa Majesté la Reine du Chef du Canada, 2012

Canada

Correct citation for this publication:

Duplisea, D.E., Power, D. and Comeau P. 2012. Reference points for eastern Canadian redfish (*Sebastes*) stocks. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/105 ii + 22 p.

ABSTRACT

Redfish, *Sebastes mentella* and *Sebastes fasciatus*, support relatively small yet important fisheries in Atlantic Canada. Canada has committed to providing a precautionary approach framework for all fisheries and redfish having just been evaluated by COSEWIC and a recovery potential assessment undertaken by DFO (McAllister and Duplisea 2011), conditions are right for PA reference point development. Here we calculate limit reference points and suggest other reference points applying a range of methods using data currently available. The primary method utilised for determining reference points was a state-space Bayesian Schaeffer surplus production model used in the RPA. In addition, empirical reference points based on properties of the survey time series were also derived where possible. Suites of reference points for stocks from various methods were then compiled. Finally, the most appropriate suites of reference points were identified through peer-review and were put forward for each stock.

RÉSUMÉ

La pêche du sébaste, *Sebastes mentella* et *Sebastes fasciatus*, est une pêche relativement petite, mais importante dans le Canada atlantique. Le Canada s'est engagé à fournir un cadre d'approche de précaution pour toutes les pêches et comme le COSEPAC vient d'évaluer la situation du sébaste et le MPO d'entreprendre une évaluation du potentiel de rétablissement (McAllister et Duplisea 2011), les conditions sont réunies pour pouvoir définir les points de référence. Nous calculons ici les points de référence limites et proposons d'autres points de référence en suivant diverses méthodes qui font appel aux données disponibles. La principale méthode appliquée pour déterminer les points de référence est un modèle bayésien de surplus de production d'espace d'état de Schaefer utilisé dans l'évaluation du potentiel de rétablissement. Des points de référence empiriques fondés sur les propriétés de la série chronologique des relevés ont également été calculés lorsque cela était possible. Des séquences de points de référence pour les stocks ont ensuite été compilées à partir des différentes méthodes. Enfin, les séquences de points de référence les plus appropriées ont été déterminées dans le cadre d'un examen par les pairs et présentées pour chaque stock.

INTRODUCTION

THE PRECAUTIONARY APPROACH (PA) FRAMEWORK IN CANADA

Under the Canadian PA framework for sustainable fisheries there are four primary elements: (1) the limit reference point (Blim) (2) the upper stock reference point (USR) (3) the removal reference or harvest control rule (HCR) (4) the target reference point (Btar) (Fig. 1).

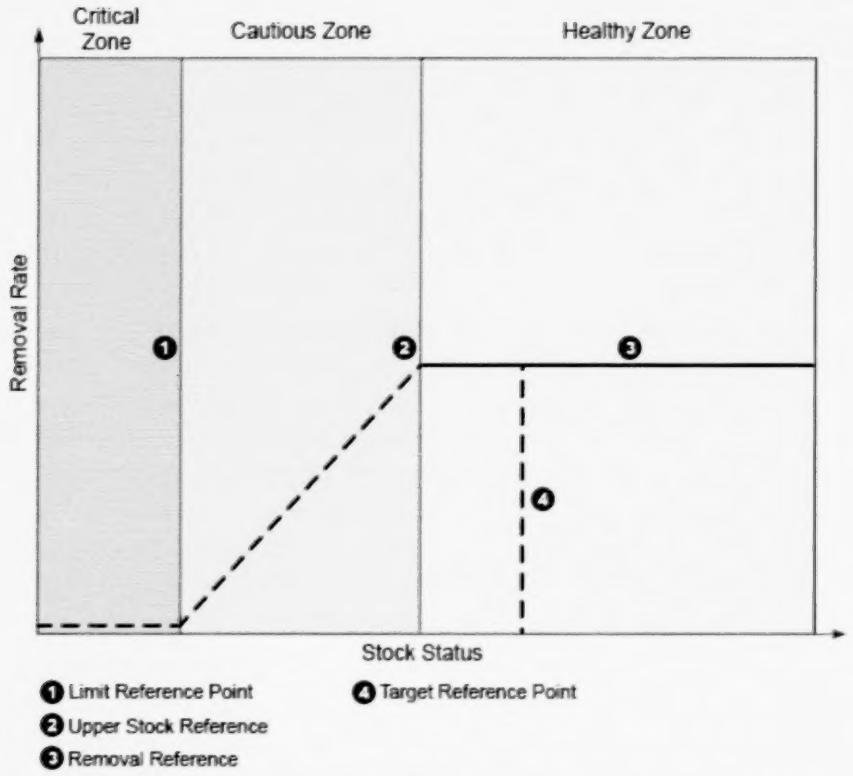

Figure 1: The Canadian precautionary approach framework for sustainable fisheries. http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm

WHO IS RESPONSIBLE FOR THE DEVELOPMENT OF COMPONENTS OF THE PA FRAMEWORK?

Under the Canadian PA framework (see Fig.1) development and estimation of each component is assigned to specific groups. Blim is considered to be a purely biologically based and defines where stock productivity is seriously impaired. As such it is estimated using a purely scientific process. USR is seen as a component that would be established primarily by industry and Resource Management with input from Science. The USR can be defined as a place such as a plateau in the stock recruit curve or a point in biomass space at which there is little benefit in terms of increased stock productivity in allowing the stock to increase above it. The USR must also be set at an appropriate distance

above the LRP to provide sufficient opportunity for the management system to recognize a declining stock status and sufficient time for management actions to have effect. Science can come up with some elements of an HCR (e.g. the plateau in removal rate in the healthy zone should generally be below Flim as judged by international norms), Btar is the mandate of management and industry. Science will help define Btar in the sense that it should be sufficiently larger than USR to ensure that the stock does not fall regularly into the cautious zone simply because it varies around the target from year to year because of uncertainty associated with the stock index. i.e. management should ensure that the target is relatively robust to uncertainty.

STOCKS AND DATA

We consider five stocks for PA framework development (Fig. 2):

1) Unit 3 *Sebastes fasciatus*
2) Unit 1 + Unit 2 *Sebastes fasciatus*
3) 2+3K *Sebastes fasciatus*
4) Unit 1+ Unit 2 *Sebastes mentella*
5) 2+3K *Sebastes mentella*

These stocks generally constitute a biological stock although they do not necessarily correspond to management units. NAFO zones 3LMNO were excluded because a reference point for the portion of the stock in the Canadian exclusive economic zone (EEZ) only was requested by fisheries management (because that portion is managed as a domestic stock). The exclusion of 3LMNO is artificial and the extent to which redfish move in and out of this zone and that recruitment dynamics of the Canadian EEZ stocks are affected by the whole stock size is unknown and could be an important source of uncertainty.

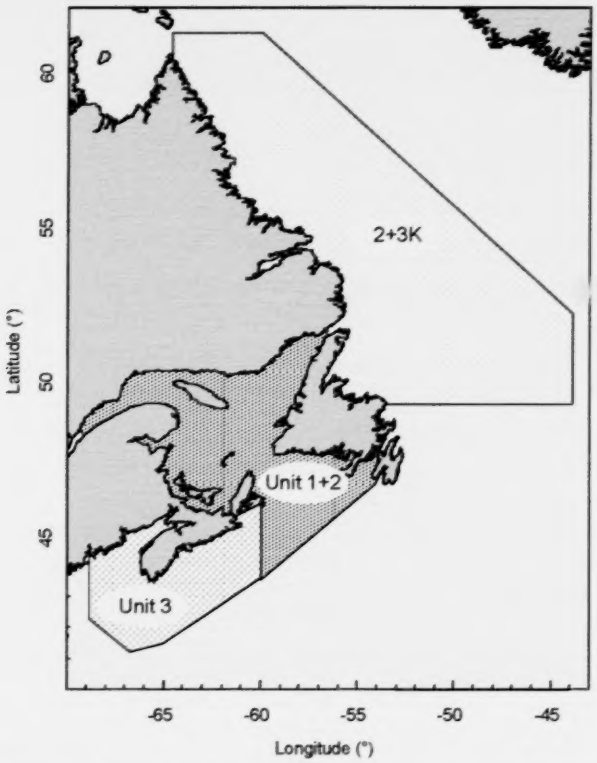

Figure 2: A map of eastern Canada roughly showing the regions encompassing the different redfish stocks requiring a precautionary approach to management.

For Unit 3, the DFO summer survey conducted from 1970-2011 is the data source for the biomass index.

In Unit 1 the primary biomass index is calculated using data from the summer survey conducted since 1990. Other surveys such as the Lady Hammond and Gadus survey were not used because they had inconsistent coverage, did not distinguish species and, in the case of the Gadus, occurred during the winter which is not considered a good time to sample redfish because a large portion of the stock migrates out of Unit 1 during winter.

The Unit 2 survey conducted by GEAC every other year starting in 2000 was the primary data source for this region. The 3P winter survey was not used because the survey was carried out in winter most years but was as late as May or June in some years. Also, it did not cover the deep strata which are the primary habitats for redfish. The 3Ps survey also did not distinguish redfish species.

The surveys in 2+3K are usually fall surveys. There were some gear changes between the Engels and Campellen trawls but these have been all converted into Campellen equivalents.

METHODS

PRODUCTION MODEL

A state-space Schaffer surplus production model with process and observation error was fitted using Bayesian methods (McAllister and Duplisea 2011, 2012). Uniform priors were used for q and K and while life history parameters were used to develop an r prior. The CV of the survey index informed a lognormal prior for observation error and process error was given a log-normal prior with sigma=0.05. Details of the modeling are documented in McAllister and Duplisea (2011, 2012).

The interpretation of the default rules in a Schaffer production model context

The DFO PA framework for sustainable fisheries lists in its appendix 1 default reference points for when detailed modeling methods such as a VPA are not available for a stock. The thinking behind these defaults is based on Bmsy and proportions of Bmsy (0.8 Bmsy and 0.4 Bmsy). These defaults have been interpreted here in terms of the Schaffer model production vs biomass curve (Fig. 3) and points can be easily derived from the Schaffer model fit. This approach to adopting reference points has been done previously in other *Sebastes* stock assessments (Yamanaka et al. 2011, McAllister and Duplisea 2011) and this approach is quite similar to the approach used in the USA to define categories such as over-exploited, fully exploited and under-exploited.

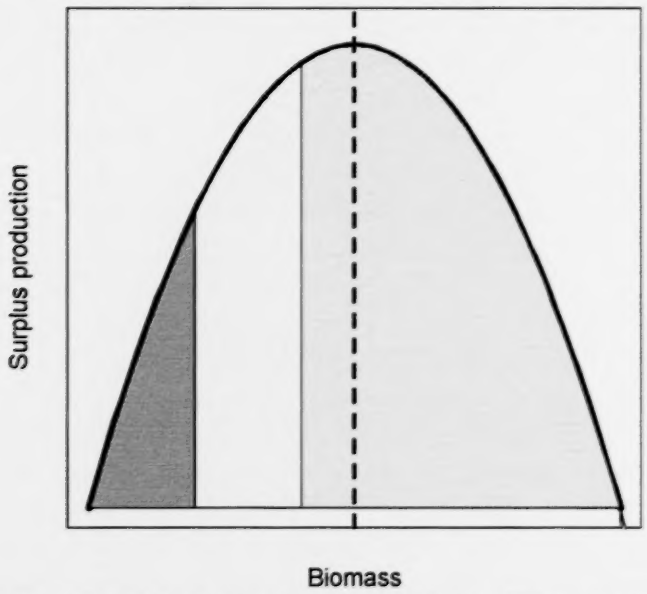

Figure 3: Interpretation of the default reference points outlined in DFO's sustainable fisheries framework in the surplus production space of a Schaeffer surplus production model. The critical zone is in red whose upper boundary is marked by the limit reference point (40% Bmsy). The cautious zone in yellow has it upper boundary determined by 80% Bmsy and the healthy zone in green is any point larger than 80% Bmsy. The target reference point is equal to Bmsy (dashed vertical line).

EMPIRICAL

Some common points to consider as well as the default framework

A variety of empirical methods can be applied to derive reference points for stocks for which no analytic model has been fitted. These points are generally derived from a survey index or a fishery CPUE index that can be considered to index biomass and not just fishery efficiency. A common limit reference point of this type is Brecover also called Bloss (Duplisea and Frechet, 2010). This is the lowest biomass from which the stock has recovered. Other proxy points are described in DFO (2009) annex 1. A number of empirical approaches to identifying reference points were applied to the redfish stocks where the trends in the survey series allowed for it.

SPLITTING OR OTHER METHODS

Within the context of the Redfish recovery potential assessment (DFO 2011) Bmsy was estimated for a large area (2+3KLNO) which includes areas managed domestically as well as areas managed by NAFO. For domestic management purposes it was decided there was a need for reference points for the Canadian areas specifically. One could refit a model to the area of interest but in the case of the 2+3K vs 3LNO there was an issue with attributing historical catch to one area or another as well as splitting the stock along political rather than biological boundaries. We therefore used the model as applied to the whole area for a total Bmsy, and then split the total Bmsy by the proportion of the stock area in the core areas of the two zones. For *S. mentella*, we estimated that about 80% of the mature biomass in the 2+3KLNO area is found in the 2+3K portion of the stock. Biomass estimates are therefore multiplied by 80% where appropriate. Reference points and catchability values from the model fitted to the entire stock complex were adjusted accordingly.

CANDIDATE POINTS TO ANCHOR THE REMOVAL REFERENCE OR HARVEST CONTROL RULE (HCR)

In addition to Bmsy, Fmsy is a point of significance that comes from the production model fitting. Fmsy should be regarded as the maximum level of fishing mortality allowed (i.e. Flim) (FAO 1995, annex II/7). Fishing at Fmsy will bring the stock to the target of Bmsy (biomass which produces MSY) and therefore is a logical target for fishing mortality in the healthy zone. A candidate for exploitation rate or F near the cautious/critical boundary, i.e. at the biomass limit reference point, could be the F that would be associated with the incidental catch or by catch from other fisheries. Such a value could be easily estimated in regions where there has been a moratorium and/or where by-catch levels are known. One might then join this F value at Blim to a proportion of Fmsy (e.g. 1/3rd) at Bmsy or USR to obtain a complete HCR as depicted in Figure 1. There is no guarantee however that this would keep the stock healthy with valuable sustainable fisheries but it is a candidate HCR to test in a management strategy evaluation context.

RESULTS BY STOCK

UNIT 3 *SEBASTES FASCIATUS*

Production model reference points

The production model fit to Unit 3 *S. fasciatus* was very uncertain because the survey index showed little response to fishery changes and changes in catch were relatively small from year to year (Fig. 4). This means that absolute estimates of reference points and stock state are very uncertain though it is possible to state that there is a very low probability of the stock biomass being below Bmsy

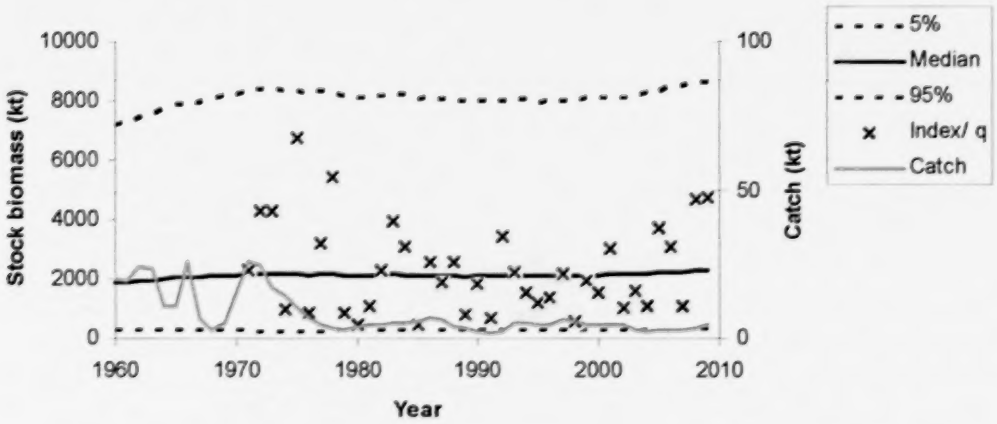

Figure 4: Median modelled mature stock biomass and catch biomass (kt), and 5th, median and 95% percentiles for mature stock biomass of S. fasciatus in Unit 3. The survey biomass indices divided by the median estimates of q are also shown.

Despite the large uncertainty about the absolute level of the stock biomass or reference points, a point for Bmsy that comes from the fittings is 1145 kt (McAllister and Duplisea 2011, table 15-median) thus 80% and 40% of this value, which could be considered candidates from the upper stock reference point and the limit reference point would be 916 kt and 458 kt, respectively. BSP production model fitting for Unit 3 *S. fasciatus* indicated an Fmsy value for this stock of 0.08 y-1 (*McAllister and Duplisea 2011*, table 15-median). To be consistent with international norms, Fmsy would be the fishing mortality limit point (i.e. maximum acceptable exploitation rate) in the healthy zone. The current exploitation rate for this stock is well below this level.

Empirical reference points

The Unit 3 Acadian redfish mature biomass index has shown large variations since 1970 but very little trend (Fig 5). The stock fell to just under 25 kt swept area biomass in several years but can increase to more than 100 kt in the next year suggesting that index is highly variable. It is difficult to derive an empirical limit point from this data but the lack of trend would suggest that biomass averaged over the series might be considered a value that is "normal". This approach produces a biomass value of 73 kt survey swept area units. 80% and 40% of these values would be the candidates for the

upper stock reference and limit reference points for this stocks which are 58 kt and 29 kt, respectively.

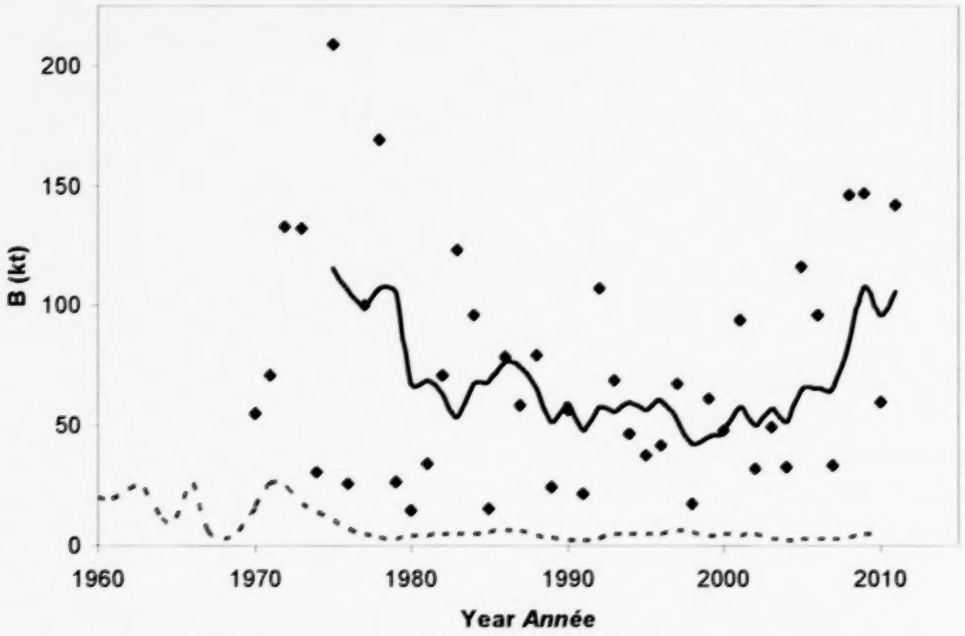

Figure 5: DFO summer survey mature biomass index for Unit 3 Acadian redfish (points) and a 5-year running average smooth through the points (solid line) and commercial catch (dashed line).

The mean biomass value over the series would appear to be something like Bmsy and this is what we have used here. Consequently, the USR and Blim values could be considered 80% and 40% of these values, respectively.

Another possibility for the Blim value could be the Brecover point from the smoothed series. In this case, it would be the lowest value in the smoother which occurred in 1998 which was 42 kt.

Finally, another empirical method for Unit 3 is to take the average of the whole time series as being representative of Bmsy and then use the 80%Bmsy and 40% Bmsy values as the Busr and Blim respectively (Fig 6). This gives a slightly smaller Blim value but has the advantage of providing suggestions for all biomass reference points.

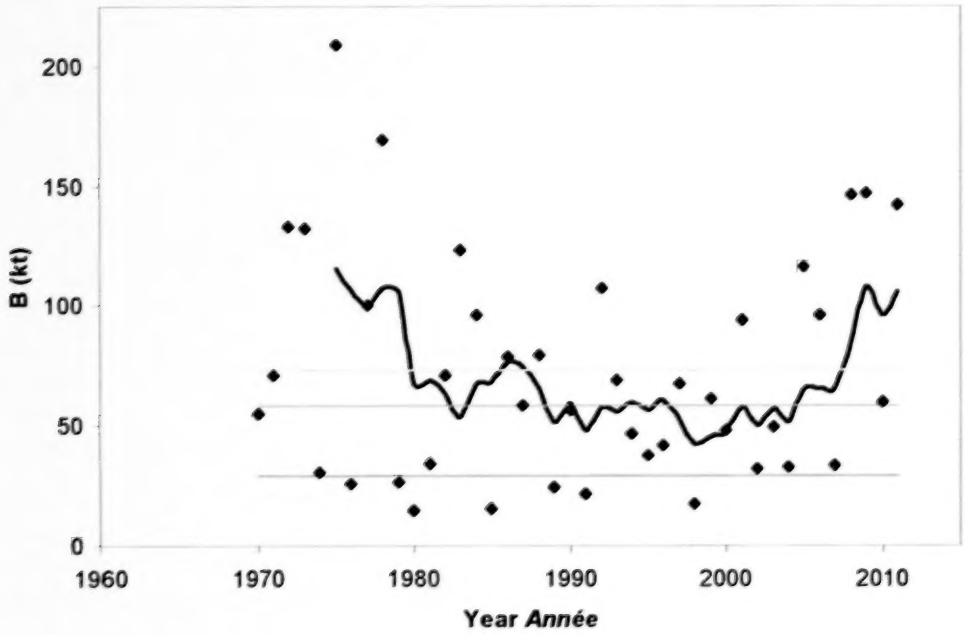

Figure 6: DFO summer survey mature biomass index for Unit 3 Acadian redfish with a five year moving average index (black line) and mean biomass level (top horizontal line 73 kt). 80% and 40% of the mean biomass value are 59 kt and 29 kt shown as the middle and lower horizontal lines, respectively.

UNIT 1+2 *SEBASTES FASCIATUS*

Production model reference points

The production model fit to *S. fasciatus* in Unit 1+2 suggests a large decline in biomass since the survey index in 1990 begins (Fig 7). The 2010 biomass stands at about 17% of Bmsy. The Bmsy estimate for the stock was estimated at 370 kt (McAllister and Duplisea 2012, Table 11 - median). This would place 80% and 40% Bmsy at 296 kt and 148 kt which are candidates for the upper stock reference point and limit reference point, respectively.

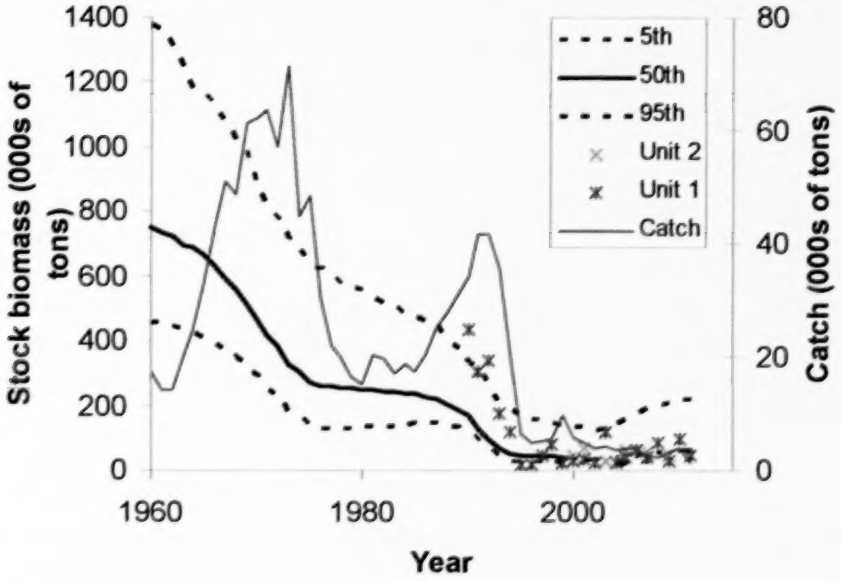

Figure 7: Median modelled mature stock biomass and catch biomass (kt), and 5th, median and 95% percentiles for mature stock biomass of S. fasciatus in Unit 1+2. The survey biomass indices divided by the median estimates of q are also shown.

BSP production model fitting for Unit 1+2 *S. fasciatus* indicated an Fmsy value for this stock of 0.06 y-1 (McAllister and Duplisea 2012, table 11 - median). To be consistent with international norms, Fmsy would be the fishing mortality limit point (i.e. maximum acceptable exploitation rate) in the healthy zone.

Empirical reference points

The survey indices in Unit 1 for *S. fasciatus* show large decline from 1990 until 1995 after which the biomass level varies from year to year at this very low level (Fig 8). As such, there is no candidate for a Blim values such a Brecover as there has never been a sign of recovery.

From these data, there is no basis for a Blim value based purely on survey indices. No other purely empirical reference point suggestions which could be proxies for USR or the target are apparent from this data series.

No empirical reference points can be derived from the Unit 2 survey series presently (Fig.9).

The Unit 2 GEAC survey for *S. fasciatus* has been conducted only every other year since 2000 and has some large variability. Presently it would be difficult to suggest defensible empirical limit reference from this series.

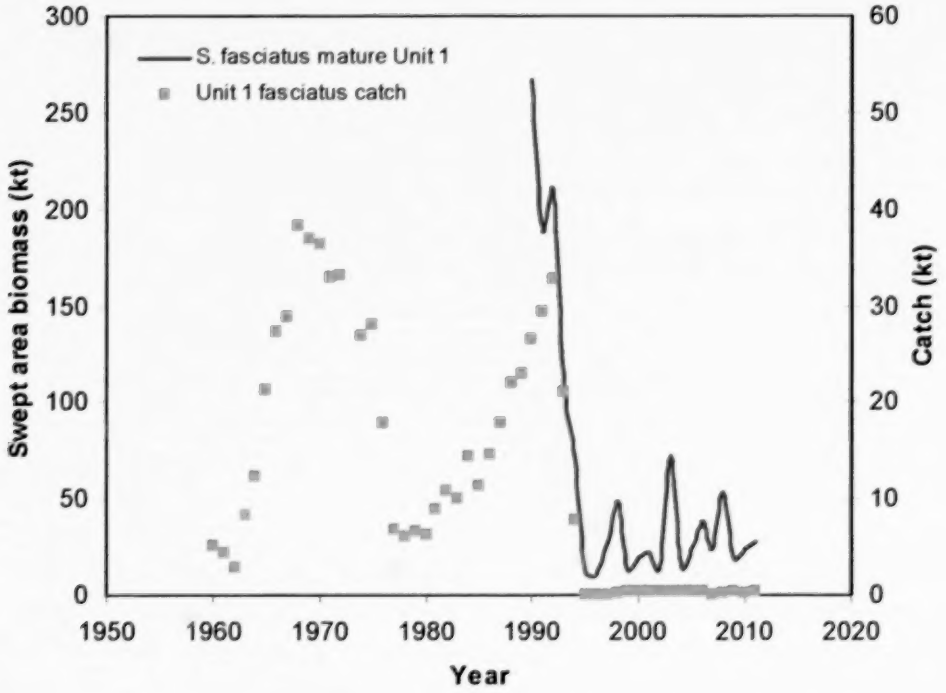

Figure 8: DFO summer survey biomass estimates for Unit 1 Acadian redfish and commercial catch

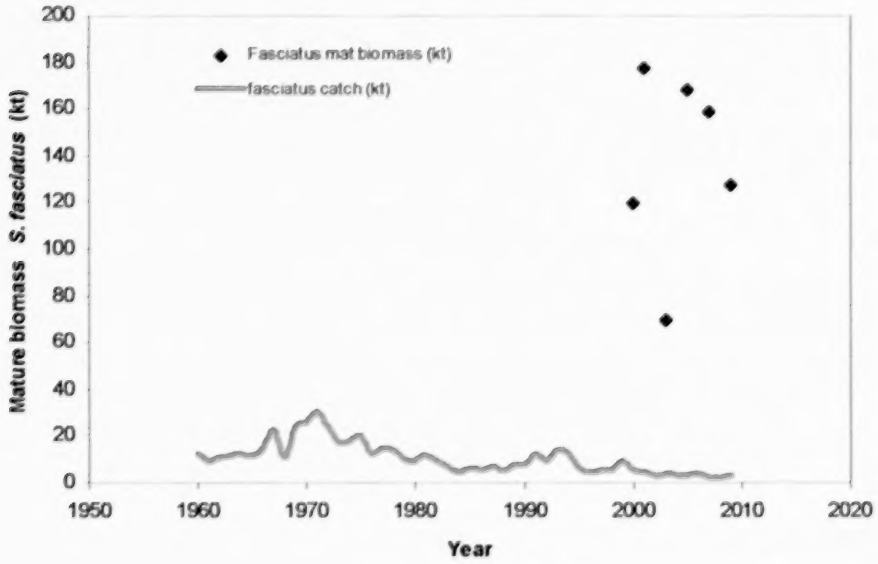

Figure 9: Unit 2 GEAC survey mature biomass and commercial catch of Acadian redfish.

2+3K *SEBASTES FASCIATUS*

Production model reference points

The modelled mature biomass for 2+3K *S. fasciatus* was relatively precise (Fig. 10). The median estimate for Bmsy for this stock from the production model was 73 kt, thus 80% and 40% of this value, which are candidates for the upper stock reference point and limit reference point where 58 kt and 29 kt, respectively (McAllister and Duplisea 2011, Table 17-median).

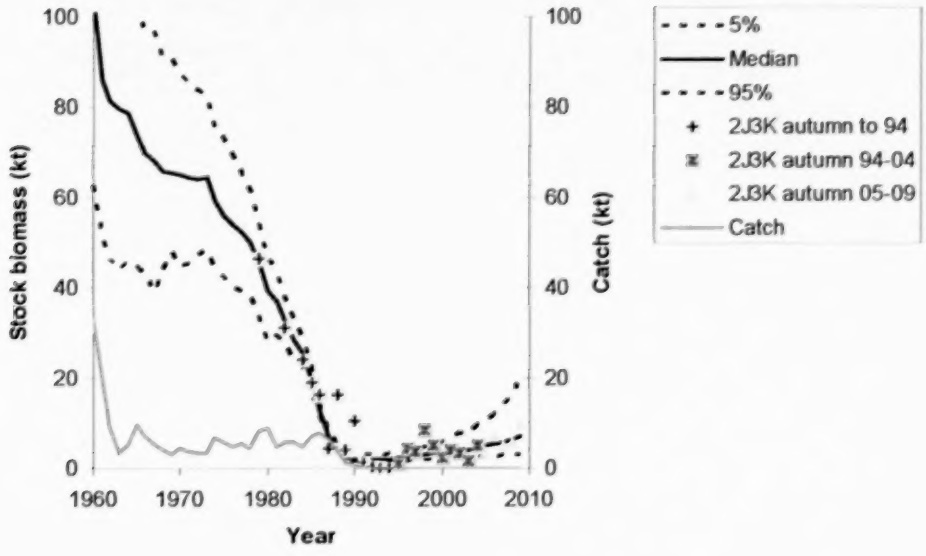

Figure 10: Median modelled mature stock biomass, catch biomass (kt), and 5th, median and 95% percentiles for mature stock biomass of S. fasciatus in 2+3K. The survey biomass indices divided by the median estimates of q are also shown.

BSP production model fitting for 2+3K *S. fasciatus* indicated an Fmsy value for this stock of 0.04 y-1 (McAllister and Duplisea 2012, Table 17-median). To be consistent with international norms, Fmsy would be the fishing mortality limit point (i.e. maximum acceptable exploitation rate) in the healthy zone.

Empirical reference points

The fall survey series for 2+3K *S. fasciatus* shows no potential candidate for a Brecover point. The 1978-1982 period showed large fluctuations which are so dramatic that they could not be due to internal growth dynamics of the stock but must rather be due to year effects (Fig. 11). Nevertheless, the mean of this period may represent a true biomass state at a time of constant catch and therefore be similar to a Bmsy value. The mean of 1978-1982 is 400 kt, 80% and 40% of this value would be 320 kt and 160 kt the three taken together would be candidates for Bmsy, Busr and Blim.

Other candidates for empirical reference points could be based on the initial survey value, i.e. an assumption that the early years of the survey could approximate virgin

Biomass (B_0). Given that biomass in the first year is near the mean of 78-82 the values are similar to those estimated above and fall at 219 kt, 175 kt and 88 kt for the target, upper stock reference and limit points, respectively. This method depends on one point from a raw survey index and it is not a very strong means of developing points especially when there are preferred alternatives.

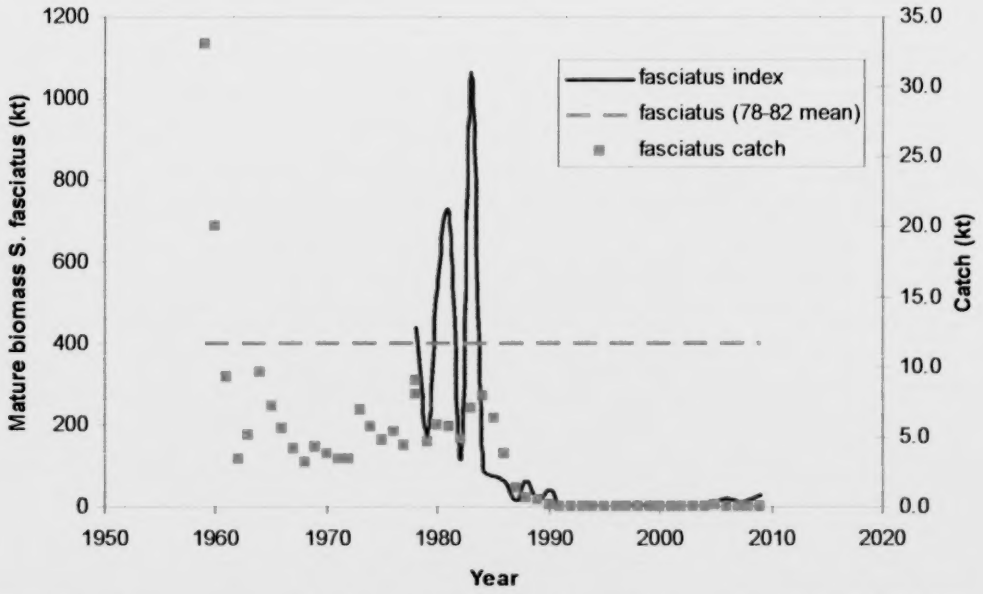

Figure 11: Survey biomass index and catch series for the 2+3K fall survey for S. fasciatus. The mean survey biomass index from 1978-1982 is shown.

UNIT 1+2 *SEBASTES MENTELLA*

Production model reference points

The modelled mature biomass for *Sebastes mentella* in the Unit 1+2 biological stock is relatively precise (Fig. 12). The median Bmsy estimate from this model was 583 kt (McAllister and Duplisea 2011 – Table 18 - median). 80% and 40% Bmsy are therefore 466 kt and 233 kt which are candidates for the upper stock and limit reference points, respectively.

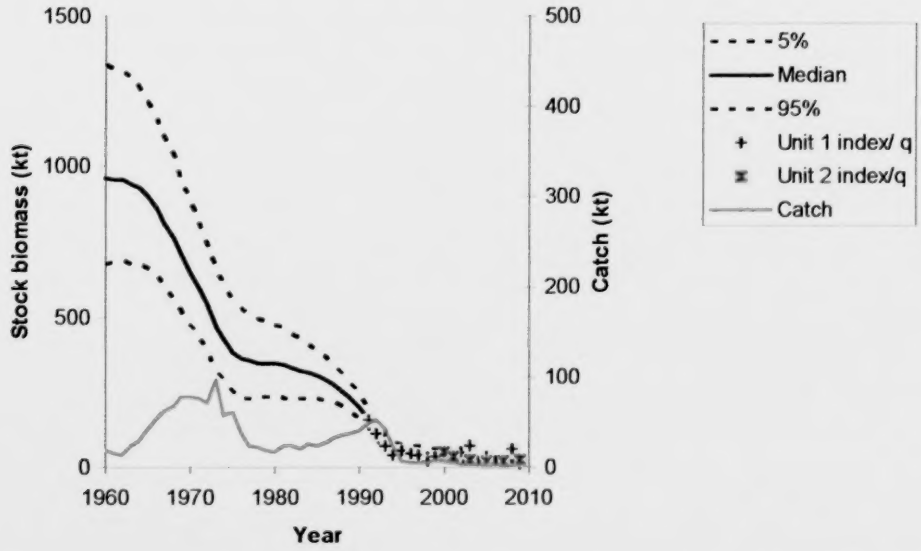

Figure 12: Median modelled mature biomass, catch biomass, and 5th, median and 95% percentiles for mature stock biomass of S. mentella in Unit 1, 2. The survey biomass indices divided by the median estimates of q are also shown.

BSP production model fitting for Unit 1+2 *S. mentella* indicated an Fmsy value for this stock of 0.03 y-1 (McAllister and Duplisea 2011, table 18 - median). To be consistent with international norms, Fmsy would be the fishing mortality limit point (i.e. maximum acceptable exploitation rate) in the healthy zone.

Empirical reference points

The survey indices in Unit 1 for *S. mentella* show large decline from 1990 until 1994 after which the biomass remains low near this level (Fig. 13). As such, there is no candidate for a Blim values such a Brecover as there has never been a sign of recovery.

From these data, there is no basis for a Blim value based purely on survey indices. No other purely empirical reference point suggestions which could be proxies for USR or the target are apparent from this data series.

The Unit 2 survey, conducted only every other year since 2000, show a decline over time until 2010 when it showed one point near the 2006 and 2004 levels (Fig. 14). Presently, there are no clear candidates for empirically derived PA reference points that could be derived from this series.

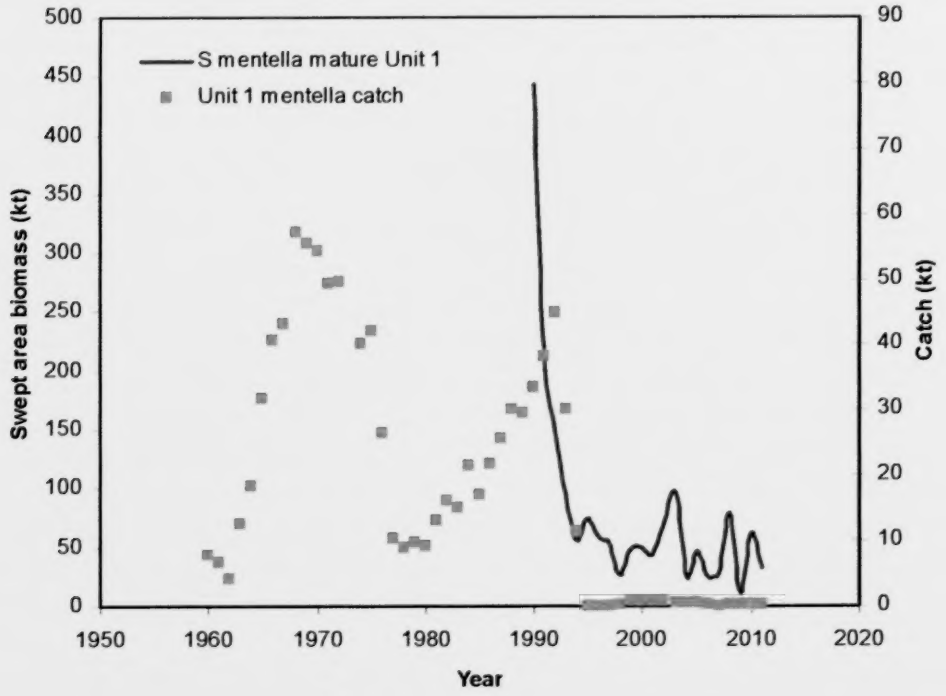

Figure 13: DFO summer survey biomass index for Unit 1 deepwater redfish and commercial catch

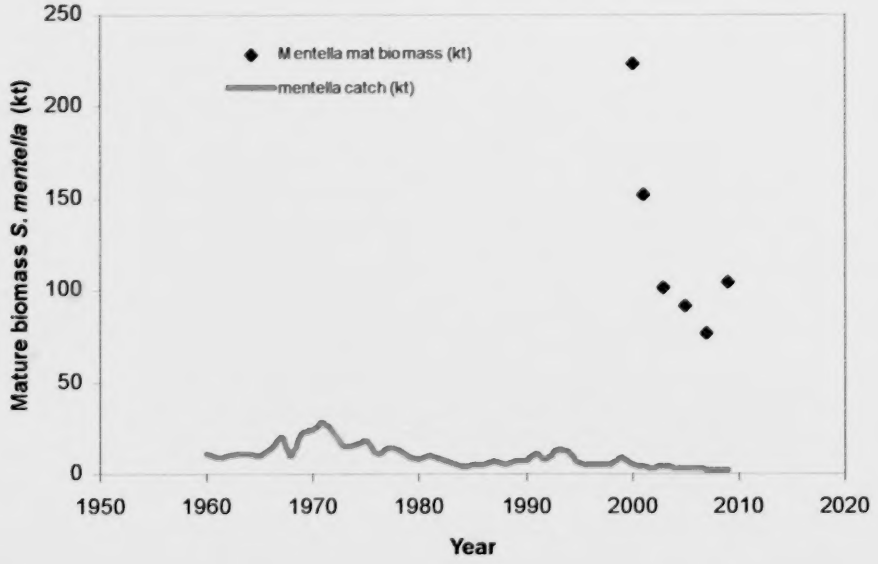

Figure 14: Unit 2 GEAC survey mature biomass index and commercial catch of deepwater redfish.

2+3K *SEBASTES MENTELLA*

Production model reference points based on partitioning regions

As mentioned earlier, the northern region *Sebastes mentella* stock was modelled to include NAFO regions 2+3KLNO for the RPA modelling work (McAllister and Duplisea 2011). As the redfish in NAFO region 3LNO are transboundary stocks, they are managed by NAFO and therefore only a reference point for the 2+3K stock needs to be developed as it is the only area where demersal redfish habitat is totally within the Canadian EEZ. For the present exercise, we applied a rough partitioning method to the results of the RPA model fitting that was considered fairly robust. Namely, we use Bmsy and its percentiles from the initial model fitting and we have partitioned those values according to the ratio of the area of 2+3K to 3LNO (Fig. 15). A design weighted area of occupancy (DWAO) index from autumn surveys was used to partition the RPA model results (Sévigny et al. 2007). We made the assumption that, within the occupied portion of each area, the density of deepwater redfish is the same in the two areas (i.e. the ratio of the size of the occupied portions of the two areas represents a ratio of the biomass in each area.) Using the above method, we calculated a Bmsy for the whole area as 363 kt (McAllister and Duplisea 2011, Table 19-median). The partitioning based on area was ~80% in 2+3K, thus the Bmsy for (2+3k) was 290 kt. 80% and 40% of this value (232 kt and 116 kt) are candidates for the upper stock reference point and limit reference point, respectively.

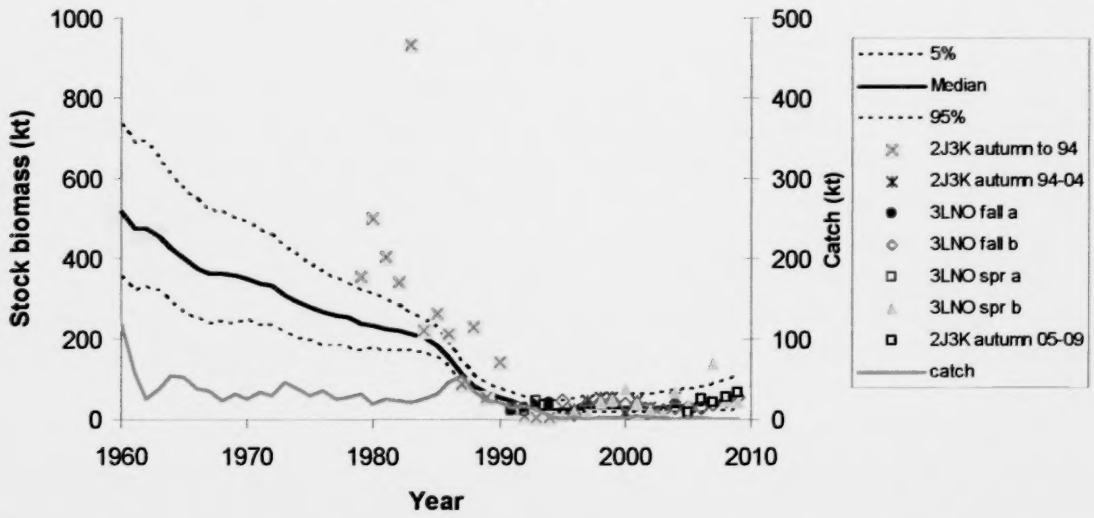

Figure 15: Median modelled mature biomass and catch biomass, and 5th, median and 95% percentiles for mature stock biomass of S. mentella in 3LNO and 2+3K. The survey biomass indices divided by the median estimates of q are also shown

BSP production model fitting for 2+3K *S. mentella* indicated an Fmsy value for this stock of 0.06 y-1 (McAllister and Duplisea 2011, table 19 - median). To be consistent with international norms, Fmsy would be the fishing mortality limit point (i.e. maximum acceptable exploitation rate) in the healthy zone.

Empirical reference points

The fall survey series for 2+3K *S. mentella* shows no potential candidate for a Brecover point. The 1979-1982 period showed large fluctuations which are so large that they could not be due to internal growth dynamics of the stock itself but rather must be attributed to year effects (Fig 16). Nevertheless, the mean of this period may represent a true biomass state at a time of constant catch and therefore similar to a Bmsy value. The mean of 1979-1982 is 494 kt, 80% and 40% of this value would be 395 kt and 198 kt the three taken together would be candidates for Bmsy, Busr and Blim.

Other candidates for empirical reference points could be based on the initial survey value in 1978 divided by 2 which then give 809 kt, 647 kt and 323 kt for the Bmsy, upper stock reference and limit points, respectively. This method depends on one point from a raw survey index and it is not a very strong means of developing points especially when there are preferred alternatives. Additionally, the 1978 survey point is a very large outlier and thus it would be difficult to justify.

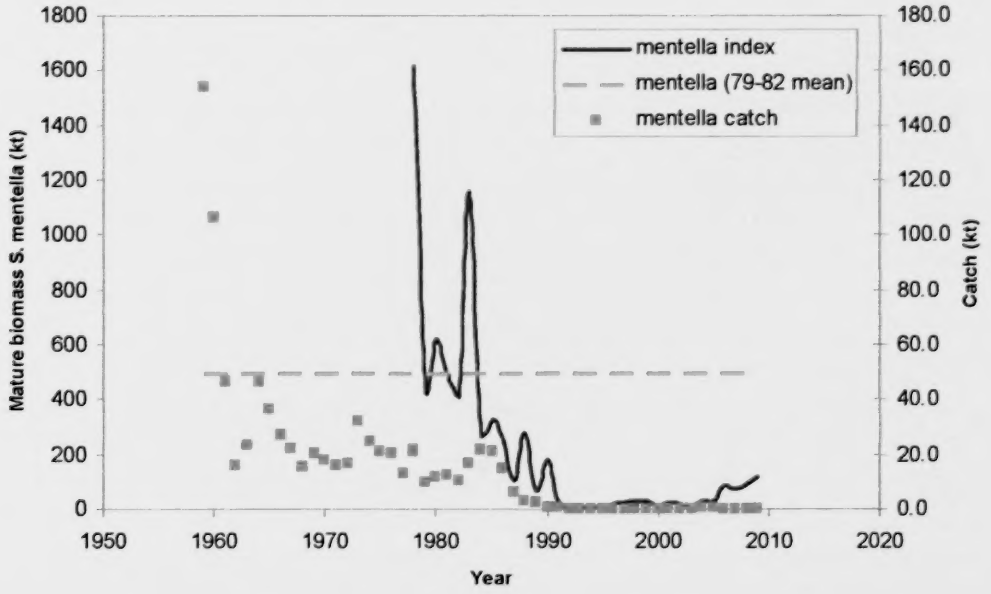

Figure 16: Fall survey biomass index for 2+3k deepwater redfish and commercial catch. The grey dotted line is the mean biomass index between 1979 and 1982.

Reference point evaluation and summary

All estimated candidate reference points are summarised in Table 1. These points are provided in suites including the LRP, USR, target, and Fmsy such that for consistency, a suite of points must be chosen, not just different ones from different suites to complete the set. In some cases the provided candidate points can be easily rejected as credible for reasons provided. In some cases, more than one credible suite of points exists for the same stock but there are still preferred options.

Table 1: Reference point estimates for five different Sebastes stocks off eastern Canada. Biomass estimates are in kt mature biomass and Fmsy estimates are per year. Suites of points are surrounded by dark lines, i.e. a consistent PA framework would in most cases need to adopt a suite and not just single values from different suites.

Stock	Point type	Point name	Name-method	Method	Estimate	Unit scale	credibility	Lack of credibility reason
2+3K *S. mentella*	target	Bmsy	Bmsy SPM fit + partition 80%	SPM fit + partition 80%	290	absolute	yes	
2+3K *S. mentella*	limit	40% Bmsy	40% Bmsy SPM fit + partition 80%	SPM fit + partition 80%	116	absolute	yes	
2+3K *S. mentella*	USR	80% Bmsy	80% Bmsy SPM fit + partition 80%	SPM fit + partition 80%	232	absolute	yes	
2+3K *S. mentella*	limit	Fmsy	Fmsy SPM model fit	SPM model fit	0.06	absolute	yes	
2+3K *S. mentella*	limit	Bloss	Bloss Survey data	Survey data	none	survey equivalents	no	no recovery observed
2+3K *S. mentella*	target	Bmsy	Bmsy Survey B0/2 1978	Survey B0/2 1978	809	survey equivalents	no	fished before 78 & 78 big outlier
2+3K *S. mentella*	limit	40% Bmsy	40% Bmsy Survey B0/2 1978	Survey B0/2 1978	323	survey equivalents	no	fished before 78 & 78 big outlier
2+3K *S. mentella*	USR	80% Bmsy	80% Bmsy Survey B0/2 1978	Survey B0/2 1978	647	survey equivalents	no	fished before 78 & 78 big outlier
2+3K *S. mentella*	target	Bmsy	Bmsy Survey Bpp 79-82	Survey Bpp 79-82	494	survey equivalents	yes	
2+3K *S. mentella*	limit	40% Bmsy	40% Bmsy Survey Bpp 79-82	Survey Bpp 79-82	198	survey equivalents	yes	
2+3K *S. mentella*	USR	80% Bmsy	80% Bmsy Survey Bpp 79-82	Survey Bpp 79-82	395	survey equivalents	yes	
Unit 1+2 *S. mentella*	target	Bmsy	Bmsy SPM model fit	SPM model fit	583	absolute	yes	
Unit 1+2 *S. mentella*	limit	40% Bmsy	40% Bmsy SPM model fit	SPM model fit	233	absolute	yes	
Unit 1+2 *S. mentella*	USR	80% Bmsy	80% Bmsy SPM model fit	SPM model fit	466	absolute	yes	
Unit 1+2 *S. mentella*	limit	Fmsy	Fmsy SPM model fit	SPM model fit	0.03	absolute	yes	
Unit 1+2 *S. mentella*	limit	Bloss	Bloss Survey data	Survey data	none	survey equivalents	no	no recovery observed
Unit 1+2 *S. mentella*	target	Bmsy	Bmsy Survey B0/2 1990	Survey B0/2 1990	222	survey equivalents	no	fished heavily before 1990
Unit 1+2 *S. mentella*	limit	40% Bmsy	40% Bmsy Survey B0/2 1990	Survey B0/2 1990	89	survey equivalents	no	fished heavily before 1990
Unit 1+2 *S. mentella*	USR	80% Bmsy	80% Bmsy Survey B0/2 1990	Survey B0/2 1990	177	survey equivalents	no	fished heavily before 1990

Table 1: Continued

Stock	Point type	Point name	Name-method	Method	Estimate	Unit scale	credibility	Lack of credibility reason
Unit 1+2 *S. mentella*	target	Bmsy	Bmsy Survey Bpp	Survey Bpp	none	survey equivalents	no	no stable and prod period
Unit 1+2 *S. mentella*	limit	40% Bmsy	40% Bmsy Survey Bpp	Survey Bpp	none	survey equivalents	no	no stable and prod period
Unit 1+2 *S. mentella*	USR	80% Bmsy	80% Bmsy Survey Bpp	Survey Bpp	none	survey equivalents	no	no stable and prod period
2+3K *S. fasciatus*	target	Bmsy	Bmsy SPM model fit	SPM model fit	73	absolute	yes	
2+3K *S. fasciatus*	limit	40% Bmsy	40% Bmsy SPM model fit	SPM model fit	29	absolute	yes	
2+3K *S. fasciatus*	USR	80% Bmsy	80% Bmsy SPM model fit	SPM model fit	58	absolute	yes	
2+3K *S. fasciatus*	limit	Fmsy	Fmsy SPM model fit	SPM model fit	0.04	absolute	yes	
2+3K *S. fasciatus*	limit	Bloss	Bloss Survey data	Survey data	none	survey equivalents	no	no recovery observed
2+3K *S. fasciatus*	target	Bmsy	Bmsy Survey B0/2 1978	Survey B0/2 1978	219	survey equivalents	no	fished before 1978
2+3K *S. fasciatus*	limit	40% Bmsy	40% Bmsy Survey B0/2 1978	Survey B0/2 1978	88	survey equivalents	no	fished before 1978
2+3K *S. fasciatus*	USR	80% Bmsy	80% Bmsy Survey B0/2 1978	Survey B0/2 1978	175	survey equivalents	no	fished before 1978
2+3K *S. fasciatus*	target	Bmsy	Bmsy Survey Bpp 78-82	Survey Bpp 78-82	400	survey equivalents	yes	
2+3K *S. fasciatus*	limit	40% Bmsy	40% Bmsy Survey Bpp 78-82	Survey Bpp 78-82	160	survey equivalents	yes	
2+3K *S. fasciatus*	USR	80% Bmsy	80% Bmsy Survey Bpp 78-82	Survey Bpp 78-82	320	survey equivalents	yes	
Unit 1+2 *S. fasciatus*	target	Bmsy	Bmsy SPM model fit	SPM model fit	370	absolute	yes	
Unit 1+2 *S. fasciatus*	limit	40% Bmsy	40% Bmsy SPM model fit	SPM model fit	148	absolute	yes	
Unit 1+2 *S. fasciatus*	USR	80% Bmsy	80% Bmsy SPM model fit	SPM model fit	296	absolute	yes	
Unit 1+2 *S. fasciatus*	limit	Fmsy	Fmsy SPM model fit	SPM model fit	0.06	absolute	yes	
Unit 1+2 *S. fasciatus*	limit	Bloss	Bloss Survey data	Survey data	none	survey equivalents	no	no recovery observed
Unit 1+2 *S. fasciatus*	target	Bmsy	Bmsy Survey B0/2 1990	Survey B0/2 1990	134	survey equivalents	no	fished heavily before 1990
Unit 1+2 *S. fasciatus*	limit	40% Bmsy	40% Bmsy Survey B0/2 1990	Survey B0/2 1990	53	survey equivalents	no	fished heavily before 1990
Unit 1+2 *S. fasciatus*	USR	80% Bmsy	80% Bmsy Survey B0/2 1990	Survey B0/2 1990	107	survey equivalents	no	fished heavily before 1990

Table 1: Continued

Stock	Point type	Point name	Name-method	Method	Estimate	Unit scale	Credibility	Lack of credibility reason
Unit 1+2 *S. fasciatus*	target	Bmsy	Bmsy Survey Bpp	Survey Bpp	none	survey equivalents	no	no stable and prod period
Unit 1+2 *S. fasciatus*	limit	40% Bmsy	40% Bmsy Survey Bpp	Survey Bpp	none	survey equivalents	no	no stable and prod period
Unit 1+2 *S. fasciatus*	USR	80% Bmsy	80% Bmsy Survey Bpp	Survey Bpp	none	survey equivalents	no	no stable and prod period
Unit 3 *S. fasciatus*	target	Bmsy	Bmsy SPM model fit	SPM model fit	1145	absolute	no/yes	uncertain fit, relative values ok
Unit 3 *S. fasciatus*	limit	40% Bmsy	40% Bmsy SPM model fit	SPM model fit	458	absolute	no/yes	uncertain fit, relative values ok
Unit 3 *S. fasciatus*	USR	80% Bmsy	80% Bmsy SPM model fit	SPM model fit	916	absolute	no/yes	uncertain fit, relative values ok
Unit 3 *S. fasciatus*	limit	Fmsy	Fmsy SPM model fit	SPM model fit	0.08	absolute	no/yes	uncertain fit, relative values ok
Unit 3 *S. fasciatus*	limit	Bloss	Bloss survey moving average	survey moving average	42	survey equivalents	yes	
Unit 3 *S. fasciatus*	USR	Bmean	Bmean survey series mean	survey series mean	73	survey equivalents	yes	
Unit 3 *S. fasciatus*	target	Bmsy	Bmsy Survey B0/2 1970	Survey B0/2 1970	28	survey equivalents	no	fished well before 1970
Unit 3 *S. fasciatus*	limit	40% Bmsy	40% Bmsy Survey B0/2 1970	Survey B0/2 1970	11	survey equivalents	no	fished well before 1970
Unit 3 *S. fasciatus*	USR	80% Bmsy	80% Bmsy Survey B0/2 1970	Survey B0/2 1970	22	survey equivalents	no	fished well before 1970
Unit 3 *S. fasciatus*	target	Bmsy	Bmsy Survey Bpp 70-11	Survey Bpp 70-11	73	survey equivalents	yes	
Unit 3 *S. fasciatus*	limit	40% Bmsy	40% Bmsy Survey Bpp 70-11	Survey Bpp 70-11	29	survey equivalents	yes	
Unit 3 *S. fasciatus*	USR	80% Bmsy	80% Bmsy Survey Bpp 70-11	Survey Bpp 70-11	58	survey equivalents	yes	

Preferred suites of reference points are provided in Table 2. For four of the five stocks, the Bayesian production model was accepted as the method for providing the reference points. Only for Unit 3 *S. fasciatus* was an empirical approach taken to setting the reference points, namely the mean biomass over the entire time series was taken as an estimate of Bmsy and other points followed accordingly.

Table 2: Summary of preferred reference point estimates, current stock biomass and growth status as well as median exit times for stocks in the critical zone. Biomass, catch levels and biomass MSY points are in kilotonnes (kt), Fmsy is per year and exit times are in years.

Stock	Accepted reference point method	Bmsy	80% Bmsy	LRP (40% Bmsy)	Fmsy	$B_{2010/11}$	Stock status	Growth status**	Catch level	Median exit time with current catch***
Unit 3 *Sebastes fasciatus*	Bmsy Survey Bpp 70-11	73*	58	29	NA	106 (2011)	healthy *	Increase	5	NA
Unit 1+2 *Sebastes fasciatus*	Bmsy SPM model fit	370	296	148	0.06	65 (2011)	critical	Increase	3	14
2+3K *Sebastes fasciatus*	Bmsy SPM model fit	73	58	29	0.04	8 (2010)	critical	Increase	0.05	23
Unit 1+2 *Sebastes mentella*	Bmsy SPM model fit	583	466	233	0.03	19 (2010)	critical	decrease	3	>60
2+3K *Sebastes mentella*	Bmsy SPM model fit	290	232	116	0.06	16 (2010)	critical	increase	1	8

*Bmsy calculated a mean biomass over the series; growth status from a 5 year moving average smooth trend; zone designation assumes that Bmsy is in the healthy zone

**determined by the catch/replacement yield in the last data year, except for Unit 3 which is empirical

***calculated by linear interpolation of stock status probability for under status quo fishing in the last reported data year for years bracketing the median probability (0.5)

For Unit 3, the BSP model fit was very imprecise and therefore there is high uncertainty around the median Bmsy value. If this high uncertainty in biomass level were not taken into account, the application of an exploitation rate to the modelled biomass to set harvest levels would be risky. An additional concern with this approach is the modelled median biomass is much higher than the index values from the survey (according to the model, survey catchability was particularly low for this stock.) We note, however, that the current stock biomass relative to Bmsy is very well estimated in BSP and it gives a 0.99 probability that the stock biomass in 2010 was above Bmsy.

We consider that the mean biomass of the survey may better represent Bmsy and the smoothed biomass indicates that the 2011 biomass is well above this value. While there is still high uncertainty in the absolute value of the biomass regardless of the method used to estimate it, there is high certainty according to both methodologies that the stock is in the healthy zone and that current catches are sustainable. The Unit 3 stock is the only redfish stock in eastern Canada for which biomass falls in the healthy zone.

The production model fits were used as the basis of determining reference points for all the other redfish stocks. The BSP model was quite precise for Unit 1+2 *S. mentella* and was

accepted for other areas. In some cases, for the model fitting, the survey indices were split into two periods and new q values estimated if survey biomass changes seemed biologically implausible, which was the case for the 2+3K stocks. There were no acceptable reference points from empirical methods for Unit 1+2 stocks. For 2+3K *Sebastes*, apparently acceptable empirically reference points could be derived as the mean of the late 1970s and early 1980s period. However, the BSP method is preferred for several reasons:

- The late 70 to early 80s mean is based on only 4-5 years of data while the BSP is based on the whole catch and survey series
- The biomass fluctuations during this late 70s early 80s period are very large and the mean may not be representative of the true populations size.
- There are known movement of fish in this area to and from the Irminger Sea (especially S. *mentella*) and it is not clear that these highly variable points in this period do not represent the effects of sampling itinerant fish.
- Bmsy estimated in this way should be done for a stable and productive period and the productive period was certainly not stable.

The suites of reference points selected for each stock represent the best choices under the present circumstances. As data series lengthen and new methods become available or are applied to these stocks then new suites may be estimated and selected. It is unlikely that for long lived species like *Sebastes* that a few more years of new data will warrant a re-estimation of reference points. New estimates would likely be required if a new and reliable assessment method is applied to the stocks and accepted as good way forward for reference point estimation.

REFERENCES

FAO.1995. Code of Conduct for Responsible Fisheries. FAO, Rome. 41 p. ISBN 92-5-103834-1

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach. October 2012 version. http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm

DFO. 2010. Assessment of redfish stocks (*Sebastes fasciatus* and *S. mentella*) in Units 1 and 2 in 2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/037.

DFO. 2011. Recovery potential assessment of redfish (*Sebastes mentella* and *S. fasciatus*) in the northwest Atlantic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/044.

Duplisea, D. and Fréchet, A. 2010. Precautionary reference point estimates for northern Gulf of St. Lawrence (3Pn4RS) cod (*Gadus morhua*) and methods for their calculation. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/097. iv + 24 p.

McAllister, M. and Duplisea, D.E. 2011. Production model fitting and projection for Atlantic redfish (*Sebastes fasciatus* and *Sebastes mentella*) to assess recovery potential and allowable harm. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/057 vi + 75 p.

McAllister, M. and Duplisea, D.E. 2012. Production model fitting and projection for Acadian redfish (*Sebastes fasciatus*) in Units 1 and 2. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/103 iii + 34 p.

Sévigny, J-M, Méthot, R., Bourdages, H., Power, D. and Comeau, P. 2007. Review of the structure, the abundance and distribution of *Sebastes mentella* and *S. fasciatus* in Atlantic Canada in a species-at-risk context: an update. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/085. x + 99 p.

Yamanaka, K.L., McAllister, M.K., Etienne, M.P., Obradovich, S.G. and Haigh, R. 2011. Stock assessment for the inside population of yelloweye rockfish (*Sebastes rubimerus*) in British Columbia, Canada for 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/129. xiv + 131 p.